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Analysis of Slope Stability using SLOPE/W Software

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Abstract. Landslide is a natural phenomenon that causes a huge threat to life and livelihood and the effects may vary from minor disruption to big catastrophes. Rainfall is an intrinsic factor for slope failure in the Western Ghats of Kerala. An increase in the frequency and adverse impact of slope failure demands slope stability analysis**.** Kerala lies in the tropical region, and is influenced by heavy monsoon rains. The present study describes the analysis of landslides that occurred at Muvattupuzha, Ernakulam district, Kerala on 27 June 2015. Detailed laboratory investigations on the soil sample were carried out to determine the index properties and engineering properties. The results of laboratory studies were utilized to perform a slope stability analysis using SLOPE/W, a limit equilibrium software. Stability analysis is conducted using the limit equilibrium method, which involves cutting the slope into a series of slices, and equilibrium equations are employed to calculate the factor of safety.

Keywords: Slope stability, SLOPE/W, Numerical modelling, Limit equilibrium

1 Introduction

Landslide is a geological phenomenon that may include downslope movement of slope material that includes rock fall, debris flow and shallow or deep-seated slope failure. The stability of the slope depends on the balance of forces acting on the slope material. Landslides are influenced by the geological condition of the soil, slope structure (slope height, slope angle), climatic change, rainfall, volcanic activities, human activities or a combination of these factors. Rainfall is a major factor responsible for slope failure. Kerala is a narrow strip of land of which 40% is occupied by the Western Ghat region. The Western Ghats often experience landslides during the monsoon season. In recent years rainfall-induced landslides have become a repeated phenomenon in Kerala. The heavy rainfall in the year 2018, 2019, 2020, 2021 resulted in numerous landslides. The landslides at Puthumala (2019), Kavalapara (2019), Pettimudi (2020), Kokkayar (2021), Plappally and Kavali (2021) were disastrous that resulted in huge loss of life and property. The effect of landslides in Kerala varied from minor disruptions to big catastrophes.

The devasting landslides occurring since 2018 showed an uneven distribution of slope failure that point to the susceptibility of the Western Ghats to landslide throughout Kerala. The Western Ghat region of Kerala is marked as a critical zone of mass movements. Several types of landslides were experienced during the monsoon season. Among which the most prominent and disastrous were the ones due to debris flow. Debris flow is the abrupt and swift downward movement of saturated overburden that contains a variety of debris, damaging and dragging everything in its path (Thampi et al. 1998). From the early 19^{th} century onwards vast areas of tropical forest and grasslands in Kerala were cleared for converting them into agricultural fields. These unsustainable practices coupled with prolonged and intense rainfall results in devasting landslides.

Stability analysis has been analyzed by two-dimensional limit equilibrium methods. An important aspect of stability analysis is the determination of the factor of safety which is the ratio of the shear strength of the soil or the shear resistance of soil to the minimal shear stress necessary to prevent slope failure. The present study evaluates the stability of the slope by SLOPE/W software that works with limit equilibrium method. The stability analysis of the slope is carried out by incorporating the data from the laboratory investigation at Kormala slope. The factor of safety determined using the software analysis gives an indication of the stability of the existing slope.

2 Study Area

The study was conducted at Kormala near Muvattupuzha at Ernakulam district in Kerala. It is located between 9º59’32.2” N, 76º34’29.4” E and 9º59’35” N, 76º34’26.8” E. The area had undergone a devasting landslide on 27 June 2015. The incident resulted in the complete collapse of a three storied building and the debris got spread over a distance of 200 m. After the landslide, the building was reduced to a pile of rubble. The landslide occurred at an elevation of 16 m and the roof of the structure landed in the middle of the road. The site location before and after slope failure is shown in Fig 1 and Fig 2. The present condition of the Kormala slope is shown in Fig 3.

Fig.1. Study location before landslide on 27^{th} June,2015

Fig.2. Study location after landslide on 27th June,2015

Fig.3. Present condition of Kormala slope

3 Objectives of the Study

The main objective of the study is to carry out an extensive evaluation of the landslide affected area and to determine the strength and safety of the existing slope. The stability analysis was conducted using SLOPE/W. The Kerala Water Authority (KWA) tank of capacity 10.5 lac litres is situated at the top of the collapsed slope. The KWA tank is the one which supplies water to 10,000 families in the town and the overburden pressure is currently posing a threat and may lead to further sliding. After the landslide, the authorities reduced the storage of the water by 50 percent as full carrying capacity may further weaken the slope. Many incidents of localized slope failure near this location were also recorded in the years of 2017, 2018, 2020 and 2021 monsoon seasons. This necessitated the study of the stability of the existing Kormala slope.

Detailed laboratory investigations on the soil sample were carried out to determine the index properties and engineering properties. The results of laboratory studies were utilized to perform a slope stability analysis using SLOPE/W.

4 Literature Review

The Western Ghat region of Kerala is considered the zone of critical mass movement. Rainfall is an extrinsic factor responsible for slope failure and the events are common during monsoons (Anbazhagan and Sajinkumar, 2011, Sajinkumar and Rani, 2015). From south to north, all 13 districts except Alappuzha is under the classification of landslide-prone area (Kuriakose, 2018). Slope instability is a concerning factor for geotechnical engineers and geologists. In recent decades a large number of softwares were developed for analysing slope stability which is either based on Limit Equilibrium (LE) Method or Finite Element Method (FEM). For decades Limit Equilibrium method was used for solving geotechnical problems.

Hammouri et al. (2008) studied the stability analysis of slopes using finite element method and limit equilibrium method with homogeneous and non-homogeneous soils. Slope stability analysis by limit equilibrium method finds difficultly in locating critical slip surfaces but due to its simplicity in analysis limit equilibrium method is the most common approach. The most common method of stability analysis is Bishop's Simplified method.

Santhosh et al. (2016) carried out work on slope stability analysis for Malin landslide in Pune, where an entire village was wiped out in the landslide. Geological and geotechnical investigations were carried out for assessing slope stability. Stability analysis is difficult without knowing slope configuration and soil parameters. In such cases efforts are made to collect information regarding field conditions and failure observations. Such methods are not appropriate if the remediation measures in slope include slope stabilizing piles. The study of failure mechanisms is important in identifying appropriate remedial solutions (Duncan1996). Stability analysis provides a quantitative measurement of the stability of an existing slope against failure. A factor of safety less than unity denotes a susceptibility to failure or unstable slope and a value greater than unity denotes stability (Chitra and Gupta, 2016).

5 Laboratory Investigation

The study involved a proper reconnaissance survey followed by site investigation and sample collections. Soil samples were collected and laboratory investigations were carried out to evaluate the index properties and engineering properties of soil at the study location. Slope parameters obtained from the site and soil properties determined in the laboratory are the controlling factors of rainfall-induced landslides. The laboratory test on the soil sample comprises of determination of moisture content, specific gravity, field density, Atterberg's limit, particle size distribution, hydraulic conductivity, shear parameters from the direct shear test, unconfined compressive strength and coefficient of compressibility from consolidation test. The results from the laboratory investigations listed in Table 1 are utilized to carry out slope stability analysis using SLOPE/W software.

Table 1. Results of laboratory Investigation.

Properties	Sample 1	Sample 2
Water content (%)	39.30	36.60
Specific Gravity	2.51	2.50
Field Density (kN/m³)	18	17
Dry Density (kN/m³)	13	12
Liquid Limit (%)	56	56
Plasticity Limit (%)	48	47
Plasticity Index	8	9
Unconfined compressive strength, kN/m² (q_u)	75	76
Cohesion, c (kN/m²)	31	34
Angle of internal friction, Ø	17	16
Coefficient of permeability (m/s)	2.55 x 10^{-5}	2.54 x 10^{-5}
Coefficient of compressibility	4.5 x 10^{-6}	4.5 x 10^{-6}

6 Numerical Assessment of Slope Stability

Numerical models are mathematical simulations of real physical process and so it is different from scaled physical models in the laboratory or full-scaled field models. The current study uses SLOPE/W for the numerical assessment. Slope stability, ground deformation, heat and mass transfer in soil and rock can be modelled using GeoStudio software. SLOPE/W is framed in terms of force and moment equilibrium to get a factor of safety equations. The primary step in stability analysis is to define the geometry of the slope. Geometry is defined with the concept of points and regions. After defining the geometry, soil strength parameters are assigned as per Mohr Coulomb model and trial slip surfaces are demarcated to establish critical modes of failure.

6.1 Model Validation

Model validation has been carried out using SLOPE/W. For validating the model, a case study of stability of mine overburden dump stabilized with fly ash (Rajak et al., 2021) was considered. The study was conducted at the open cast coal mine of Mand Raigarh coalfield, Raigarh, Chhattisgarh where the slope height has been varied from 30 m to 50 m at an interval of 5 m. The variation in the factor of safety is shown in Fig 4. The percentage error between the original analysis and current study is less than 2%, which is acceptable. Thus, it is evident that the numerical procedure adopted in this study is capable of carrying out complex slope stability analysis.

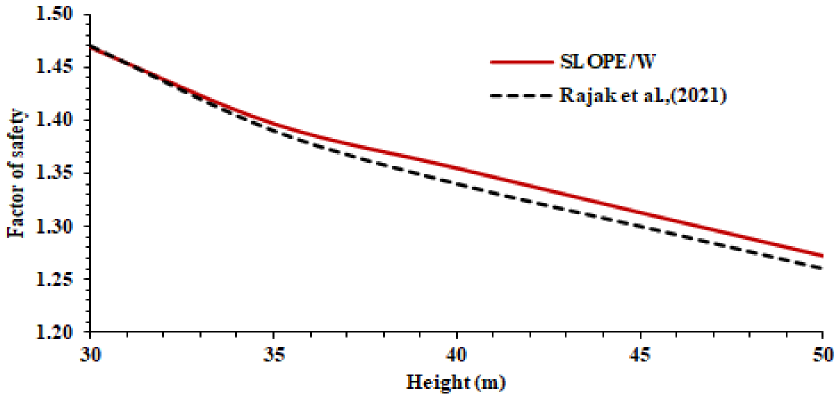

Fig. 4. Variation of the factor of safety for different heights

6.2 Slope Stability Analysis Using SLOPE/W

The stability of Kormala slope is numerically evaluated using GeoStudio software. The slope of height of 12 m and a slope angle of 76º is modelled in SLOPE/W. The slope is modelled as uniform soil and the soil properties obtained from the laboratory tests and used in the analysis are given in Table 1. Soil strength parameters are defined using the Mohr-Coulomb model. A surcharge load of 100 kN/m² is applied at the top surface. Entry exit function is used to find the slip surface. Factor of safety for each step is calculated by Morgenstern- Price method. The model geometry used in SLOPE/W is shown in Fig 5.

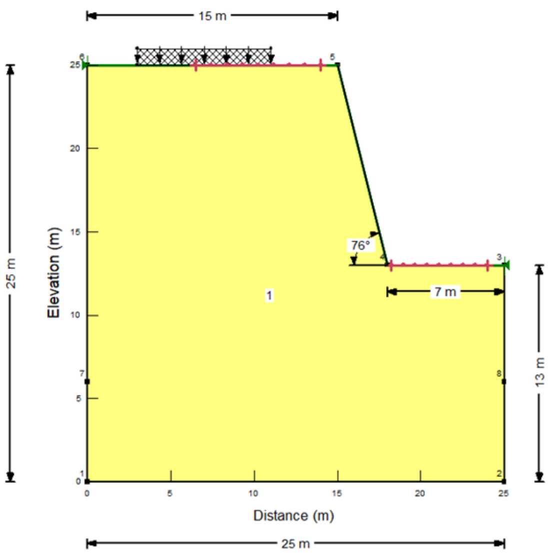

Fig. 5. Model geometry used in SLOPE/W

6.3 Results and Discussion

The results obtained from the stability analysis of sample 1 and sample 2 are shown in Fig 6 and Fig 7.

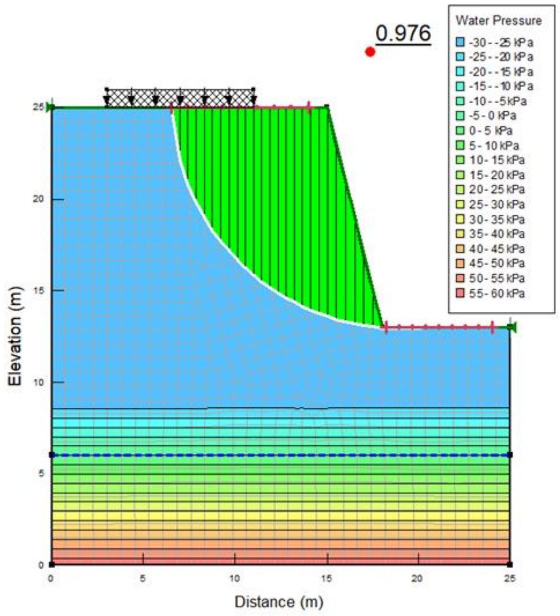

Fig. 6. Model geometry used in SLOPE/W (Sample 1)

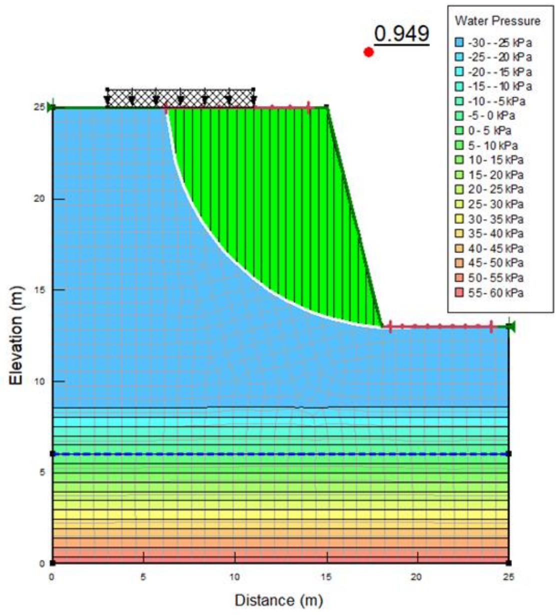

Fig. 7. Model geometry used in SLOPE/W (Sample 2)

The factor of safety obtained on stability analysis on sample 1 and sample 2 are 0.976 and 0.949 (FOS<1) respectively. A factor of safety less than unity indicates an unstable slope. A comparison of results obtained on stability analysis of sample1 and sample 2 reveals that the slope is unstable. From Fig 6 and Fig 7, it is clear that the slip surface intersects the toe of the slope, hence it can be concluded that there is a possibility of toe failure at Kormala slope. In general toe failure is observed in steep slopes when the soil mass above and below the base is homogeneous (Ranjan, Gopal, and A. S. R. Rao, 2007).

7 Conclusion

The present study aimed to evaluate the stability of an existing slope at Kormala. For stability analysis, the geometry of the slope was measured and the properties of the soil was determined for the soil samples collected from the location. A detailed laboratory investigation was performed for determining the index and engineering properties of soil at Kormala slope. Numerical assessment was performed using the SLOPE/W software using the soil properties obtained from laboratory experiments. Slope stability analysis of Kormala slope indicates that the slope is unstable under present condition. The factor of safety obtained on numerical assessment of sample 1 and sample 2 are 0.976 and 0.949 respectively which is less than unity. As the slope has already undergone a slide, the probability of further landslide occurrence is higher. Hence, a proper stabilization method is required to be adopted to avoid any further landslide in the area. At the crest portion of Kormala, it is surcharged with the KWA water tank and any further landslide in the area can lead to the collapse of the tank which can be hazardous to the people travelling on the road beneath in addition to affecting the water supply in the locality.

Preventative measures and construction procedures are necessary to prevent slope failure. Any of the following methods can be adopted.

- Installation of soil nails or ground anchors with shotcrete. These may be used to secure loose surficial deposits to harder underlying layers.
- Use of gabion mattress.
- Reinforced Earth Technique with coir geotextile as soil reinforcement.

References

1. Chitra, R., Gupta, M., 2016. Geotechnical Investigations and Slope Stability Analysis of a Landslide. International Journal of Engineering Research & Technology 5(2), pp. 390-398.
2. Fawaz, A., Farah, E., Hagechehade, F., 2014. Slope stability analysis using numerical modelling. American Journal of Civil Engineering, 2(3), pp. 60-67.
3. Ranjan, Gopal, and A. S. R. Rao., 2007. Basic and applied soil mechanics. New Age International.
4. Fredlund, Delwyn G., and R. E. G. Scoular., 1999. Using limit equilibrium concepts in finite element slope stability analysis. In International Symposium on Slope Stability Engineering, Matsuyama, Shikoku, Japan, pp. 31-47.
5. Khabbaz, H., Fatahi, B., Nucifora, C., 2012. Finite element methods against limit equilibrium approaches for slope stability analysis. In Australia New Zealand Conference on Geomechanics, Geomechanical Society and New Zealand Geotechnical Society.

6. Kumar, M., Krishnaveni, V., Muthukumar, S., 2021. Geotechnical Investigation and Numerical Analysis of Slope Failure: A Case Study of Landslide Vulnerability Zone in Kolli Hills, Tamil Nadu. Journal of the Geological Society of India, 97(5), pp. 513-519.
7. Kuriakose, S. L., Sankar, G., Muraleedharan, C., 2009. History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala, India. Environmental geology, 57(7), pp. 1553-1568.
8. Ramasamy, S. M., Gunasekaran, S., Saravanavel, J., Joshua, R. M., Rajaperumal, R., Kathiravan, R., Muthukumar, M., 2021. Geomorphology and Landslide Proneness of Kerala, India A Geospatial study. Landslides, 18(4), pp. 1245-1258.
9. Rajak, T. K., Yadu, L., Chouksey, S. K., Dewangan, P. K., 2021. Stability analysis of mine overburden dump stabilized with fly ash. International Journal of Geotechnical Engineering, 15(5), pp. 587-597.
10. Sajinkumar, K. S., Anbazhagan, S., Pradeepkumar, A. P., Rani, V. R., 2011. Weathering and landslide occurrences in parts of Western Ghats, Kerala. Journal of the Geological Society of India, 78(3), pp. 249-257.
11. Sajinkumar, K. S., Asokakumar, M. R., Sajeev, R., Venkatraman, N. V., 2017. A potential headward retreat landslide site at Munnar, Kerala. Journal of the Geological Society of India, 89(2), pp. 183-191.
12. Santosh, N., & Borole, S. M., Satish, K., 2017. Slope stability analysis with GEO5 software for Malin landslide in Pune (Maharashtra). Global Journal of Engineering Science and Researches, pp. 9-16.
13. Senthilkumar, V., Chandrasekaran, S. S., Maji, V. B., 2018. Rainfall-induced landslides: case study of the Marappalam landslide, Nilgiris District, Tamil Nadu, India. International Journal of Geomechanics, 18(9).
14. Shah, C. R., Sathe, S. S., Bhagawati, P. B., Mohite, S. S., 2021. A hill slope failure analysis: A case study of Malingoan village, Maharashtra, India. Geology, Ecology, and Landscapes, 5(1), pp.1-6.